A SUMMARY REPORT OF THE TOPEX/POSEIDON VERIFICATION WORKSHOP

Lee-Lueng Fu, Edward J. Christensen

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

Michel Lefebvre, Yves Menard

Centre National d'Etudes Spatiales, 31055 Toulouse, Cedex, France

--- Introduction -----

The joint U.S/France TOPEX/Poseidon satellite (see Eos, August 27, 1991, page 319; Eos, September 29, 1992, page 419) was launched on August 10, 1992. Orbiting at an altitude of 1336 km with an inclination of 66 degrees, the satellite has been measuring the global sea surface height using a radar altimeter system along the same tracks on Earth every 10 days since late September, 1992. The major goal of the mission is to make precise measurement of the height of the sea surface for the study of the dynamics of large-scale ocean circulation. Additionally, the data are useful for studying ocean tides and marine geophysics. The radar altimeter also measures wave height and wind speed.

At the end of the Verification Phase of the mission, a workshop was held on February 22-25, 1993 at the Jet Propulsion Laboratory in Pasadena, California to evaluate the mission's performance. About 150 scientists and engineers participated. Thirteen 10-day cycles of preliminary data, called the Interim Geophysical Data Records (IGDR), had been distributed to the Science Working Team (SWT) for their analysis prior to the

workshop. The results of the meeting indicate that all the measurement objectives have been met. In fact, many measurements have exceeded performance requirements. Therefore TOPEX/Poseidon has had a successful beginning and is well underway to its 3-5 year mission .

The objectives of the workshop were (1) to review the initial performance of the mission in terms of both engineering assessment and measurement system verification; (2) to provide feedback to the Project on the maturity of the various systems for producing the final data product - the Geophysical Data Record (GDR); (3) to make recommendations to the Project on the operation of the two altimeters onboard: the NASA dual-frequency altimeter (ALT) and the CNES solid-state single-frequency altimeter(SSALT); (4) to review early science results; (5) to discuss and formulate future science plans.

---- Measurement Performance ------

Based on the workshop results, the root-mean-square (rms) uncertainty of the altimeter range measurement under normal sea-state conditions (i.e. 2 m significant wave height and 0.1 wave skewness) is estimated to be less than 4 cm for both ALT and SSALT (including all the media and sea-state effects but excluding the altimeter height bias and bias drift) . The difference between ALT and SSALT primarily lies in the correction for the altimeter path delay in the ionosphere. The dual-frequency measurements of ALT allow the ionospheric path delay to be retrieved directly. When SSALT is in operation, the ionospheric path delay is estimated from the slant-range measurements made by an instrument called DORIS, which is a dual-frequency receiver for radiometric tracking of the satellite. The global rms difference between the two ionospheric corrections is estimated to be about 2 cm with the largest differences generally in the tropics.

The determination of the sea surface height from satellite altimetry requires precise knowledge of the height of the satellite relative the the center of the Earth. Therefore precision orbit determination (POD) is a crucial element of the TOPEX/Poseidon measurement system. A state-

of-the-art model of the Earth's gravity field was developed before launch for the POD effort of the mission. The rms uncertainty of the radial height of the orbit computed by using this pre-launch model. was estimated to be 8 cm, with geographically correlated component less than 3 cm. This orbit accuracy represents an unprecedented achievement in space technology. The orbit error in previous altimetric missions was at least 20-30 cm. It is expected that the orbit error will be further reduced after tuning the gravity model using the T/P tracking data.

The rms error for the resulting single-pass sea surface height is thus about 9 cm (the root-sum-square of 4 cm and 8 cm), significantly smaller than the prelaunch specification of 13.7 cm. However, these estimates must be deemed preliminary because of the limited amount of data analyzed. The altimeter range accuracy is dependent on the accuracy of many corrections, some of which are still being analyzed and refined.

---- Data Products -------

The SWT considered all the project systems ready for proceeding with the GDR production. Only minor modifications to the science algorithms were required to improve data quality. With the modifications implemented, the distribution of the GDR began in late May by both JPL's PO-DAAC (Physical Oceanography Distributed Active Archive Center) and France's AVISO (Archivage, Validation, Interpre'tation des donne'es des Satellites Oce'anographiques). The data are also available to the general science community upon request to either PO-DAAC (US, Japan, and Australia) or AVISO (Europe).

The SWT also noted that the data flow of the IGDR had been extremely efficient. The daily quick-look NASA data were available electronically within 5 days on PO-DAAC's computer. Tapes of 10 days' worth of the NASA data were distributed to the PI generally within 12 days. The merged data (containing both the NASA and CNES data) were distributed by AVISO in the form of CD-ROMs generally within 30 days. The distribution of the IGDR was nearly 100 %, as opposed to the pre-launch specification of 40 % for verification work. As the result of an

extra effort on the Project's part (conducted within budget) to improve the data quality, the accuracy of the orbit on the IGDR was on the order of 15 cm, as opposed to the prelaunch specification of 5 m! For the Observational Phase of the mission (the remainder of the mission), the SWT recommended the continuation of this high-quality IGDR data stream (including the electronic availability of the quick-look CNES data), which would be very valuable for environmental monitoring and operational applications.

--- Operation of the Two Altimeters ------

Because ALT and SSALT share the same antenna, only one of them can be in operation at a given time. Due to the experimental nature of SSALT, its operation time was limited to 12.5 % during the Verification Phase. In this phase, the maximum period of continuous operation of SSALT was 3 days. It was felt that complete cycles of I.O-day SSALT data were more desirable for science applications as well as certain performance evaluation (e.g., the sea-state bias). Therefore, the SWT recommended that SSALT be in operation for one complete 10-day cycle approximately every 10 cycles, with the exact schedule to be determined so as to minimize the residual ionospheric errors (after correction using the DORIS data). Coordination with certain field campaigns to validate SSALT was also recommended. This recommendation has been adopted for revising the plan for future operations.

--- Science Working Team Presentations -----

There were 38 papers presented in the workshop by the SWT members. The topics included the following: estimation of global dynamic topography, global crossover analysis, spectral analysis, sea-state bias, comparison with ERS-1 and in-situ observations as well as numerical models, wind speed and wave height evaluation, tide models, regional high resolution geoid, orbit error assessment, terrestrial reference frames, inverted barometer effect. Although there are still a number of unsettled issues such as the sea-state bias, some unexpected differences in wavenumber spectrum between ALT and SSALT height

measurements, uncertainty in the altimeter height bias, and a bias in the normalized radar backscatter coefficient (sigma-O), the general conclusions support an unprecedented accuracy of TOPEX/Poseidon data. For instance, various calculations suggest that 10-day global crossover difference is 10-15 cm, without any orbit error corrections. This is consistent with the 9 cm accuracy assessment, given that the crossover difference also accounts for residual tidal errors and other real sea level variations.

--- Science Publications and Future Meetings -----

The SWT has adopted a general plan for publications of the mission results. The results of geophysical verification from the workshop will be published in a special issue (or section) of the Journal of Geophysical Research. The data base for these publications ought to be based on the final GDR algorithms. Therefore, most of the work presented in the workshop needs to be reexamined using the GDR. Assuming that 10 cycles of the GDR will have been distributed by mid July, the earliest possible time for these publications would be the next spring. To provide an overview of the early science results from the mission to a wider and more general audience than that of JGR, a selection of papers will be solicited for publication in Science. Another JGR special issue is also contemplated for the results reported in the next science meeting.

The next SWT meeting will take place in conjunction with the second JASO (Journees Altimetrie Spatiale pour l'Oceanographic) "Satellite Altimetry for Oceanography", November 29 - December 3, 1993, in Toulouse, France. The first two days will be dedicated to the SWT meeting, followed by a 3-day general symposium. Circulars about the meeting are available from Michel Lefebvre (M.Lefebvre/Omnet) .

--- Future Missions ------

Given the very promising results obtained by the TOPEX/Poseidon

mission at the end of the Verification Phase and given the need to maintain observations of the ocean circulation and sea level changes over decades to help understanding climate changes, the SWT recommended that a series of altimetric missions with the TOPEX/Poseidon level of accuracy or better be implemented in order to ensure the continuity of high-accuracy altimetric measurements on the long-term. A summary of ongoing studies of future satellite altimeter missions by NASA, CNES, and NOAA was presented. The SWT recommended that NASA, NOAA and CNES take the appropriate steps to design, develop and implement such a system in due time as a joint contribution to the Global Ocean Observing system .

The SWT, which is also the interim science team for the radar altimeter on the EOS Altimeter Platform, discussed the payload issues for the EOS Altimeter Platform. Because of the discrepancies in orbit requirement between the radar altimeter and the laser altimeter on this platform, the SWT recommended that the EOS radar altimeter instruments should be flown separately from the laser altimeter.

The SWT also recommended the development of a gravity mapping mission to be launched before the end of 1998. This mission should substantially improve the resolution of the geoid, so that measurements from TOPEX/Poseidon and follow-on radar altimeter missions could more accurately determine the quasi-geostrophic circulation of the upper ocean.

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